

# Generalized Quantum Theory, Contextual Emergence and Non-Hierarchic Alternatives

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## Abstract

The concept of emergence is critically analyzed in particular with respect to the assumed emergence of mental properties from a neuronal basis. We argue that so-called contextual emergence is needed to avoid an eliminatory reductionism. Quantum-like features of the emergent qualities are to be expected. As a consequence, non-causal relations like entanglement correlations have to be considered as full fledged elements of reality. "Observable extension" is proposed as a contextual alternative to emergence avoiding the asymmetry between purportedly basic and emergent properties.

## 1 Introduction

By convention sweet, by convention bitter, by convention hot, by convention cold, by convention color: but in reality atoms and void. This is the first and for all times prototypal formulation of a reductionist world view given in the fifth century B.C. by Democritus from Abdera. The endeavor is understanding the world in terms of a limited number of "primary qualities" of a basic layer of reality like positions and velocities of atoms and reducing "secondary qualities" of a somehow subordinate ontological status like color and smell to the primary ones. For good reasons, some version of physical reductionism is a widespread if not dominant attitude in contemporary science. It offers an attractive reduction of complexity in understanding large parts of our world and it takes profit from the impressive success of

physics in exactness, certainty, coherence and applicability. The reduction of thermodynamics to mechanics is often considered as paradigmatic for the success of a reductionist program. (But see our discussion in Section 3.) *Neuronal reductionism* as a strategy of understanding mental phenomena in terms of neuronal activities has many vigorous proponents. This is another example of a physical reductionism, because the possibility to understand neuronal activity in physical terms is generally accepted.

*Eliminative reductionism* is an extreme form of reductionism attributing reality only to the basic layer. For instance, eliminative neural reductionism [1] attributes to the "popular psychology" terminology only the meaning of an incomplete shorthand notation for the true and exact neuronal description. This radical view is rarely adopted and will not be discussed further. Much more widespread is *emergentism*, an attitude granting to notions of the secondary, "higher", "emergent layer" its own although ontologically somehow subordinate status. The claim is that systems described in terms of the basic layer will develop new and surprising features once a certain threshold of complexity is passed. Many versions of emergentism are advocated reaching from a milder form of reductionism up to a decidedly anti-reductionist attitude. In more formal terms, the question of the interpretation of emergentism becomes a problem of the specification of the relationship between two different descriptions or modelisations of a part of reality, one of them considered "basic" and one considered "emergent". Three questions are of particular interest in this context. (1) What is the ontological status of the emergent layer? (2) What is the novelty status of the emergent layer? (3) What about the possibility of "downward causation" from the emergent to the basic layer. Approaching these questions we shall proceed as follows: (More material can be found in [2].)

First we shall present a very general formal scheme for describing and modelling systems of most general type. It has been developed under the name of "Weak" or *Generalized Quantum Theory* (GQT) [3, 4, 5] arising from physical quantum theory by shedding off all formal features pertaining to physics in the narrow sense and thus widening the range of applicability beyond physics still keeping salient quantum notions like complementarity and entanglement. GQT can be seen to be in direct accordance with basic categorial fundamentals of the human cognitive system. GQT strongly suggests that quantum-like features of systems are generic and that the ontological constitution of systems in classical physics should be considered exceptional. This message is noteworthy, because neuronal emergentism is normally inspired by a classical or even mechanistic world model.

Next we shall critically analyze the standard example of the emergence of thermodynamics and arrive at the notion of *Contextual Emergence* [6, 7]. Then we shall investigate to what extent neuronal emergence fulfills the criteria of Contextual Emergence.

Finally, we propose *observable extension* as a more symmetric alternative to the hierarchical concept of emergence and give tentative answers to the three questions raised

above.

## 2 Generalized Quantum Theory

World is never given to us directly but primarily only as it appears on our internal stage. Naive realism assumes that the world, at least in essence, really is like it appears to us. This is a very strong assumption underrating the active role of the human cognitive system and the human activity as a "model builder". The preferred world model of contemporary physical and neuronal reductionism exhibits the influence of classical mechanics and is in danger to confuse a world model with the world itself.

In fact the appearance of the world is bound to fundamental *existentials*, constitutive features of our human mode of existence and thereby also categorial elements of human cognition, similar to Kant's categories. Four of them are of particular importance for us: (For more details see [8])

1. *Excentricity/oppositeness*: Every perception or cognition of the form accessible to us is irrevocably bound to the figure of oppositeness by always being the perception or cognition of something by someone. The *epistemic cut* separating the "observer" from the "observed object" may be movable but it is never completely removable.
2. *Temporality*: The world is not given to us in the mode of a timeless panoramic picture but rather like a movie or a temporal sequence of events which occur in the running window of a distinguished "now".
3. *Facticity*: We do not so much live in a world of potentialities but rather in a world of facts, which hit on us and occur to us. The "now" is of prototypal facticity.
4. *Freedom and causality* are not in contradiction but offshoots from the same root of temporality differentiated into past, present and future. They rely on each other: Causality is required for freely chosen actions to have predictable effects and causal regularities are detected by freely creating causes and observing their effects.

Weak or *Generalized Quantum Theory* (GQT) [3, 4, 5] is a conceptual core of quantum theory, which arose from an axiomatic formulation of physical quantum theory by leaving out all features which seemed to be special to physical systems. As we shall see, it takes into account the above existential universals right in the heart of its structure. GQT is not physics but a very general theory of the structure of observed systems. For the purposes of this note, it suffices to give a short account of the vital structural features of GQT. For recent developments and applications see [5, 9].

The following notions are taken over from quantum physics:

*System*: A system is anything which can be (imagined to be) isolated from the rest of the world and be subject to an investigation. A system can be as general as "impressionism", a school of art together with all persons involved in production and interpretation. Unlike the situation in, e.g., classical mechanics the identification of a system is not always a trivial procedure but sometimes a creative act. In many cases it is possible to define *subsystems* inside a system.

*State*: A system must have the capacity to reside in different states without losing its identity as a system. One may differentiate between *pure states*, which correspond to maximal possible knowledge of the system and *mixed states* corresponding to incomplete knowledge.

*Observable*: An observable corresponds to a feature of a system, which can be investigated in a more or less meaningful way. *Global observables* pertain to the system as a whole, *local observables* pertain to subsystems. In the above-mentioned example, observables may, for instance, correspond to esthetic investigations.

*Measurement*: Doing a measurement of an observable  $A$  means performing the investigation which belongs to the observable  $A$  and arriving at a result  $a$ , which can claim *factual validity*. What factual validity means depends on the system: Validity of a measurement result for a system of physics, internal conviction for self observation, consensus for groups of human beings. The result of the measurement of  $A$  will in general depend on the state  $z$  of the system before the measurement but will not be completely determined by it.

Immediately after a measurement of an observable  $A$  with result  $a$ , the system will be in an *eigenstate*  $z_a$  of the observable  $A$  with *eigenvalue*  $a$ . The eigenstate  $z_a$  is a state, for which an immediate repetition of the measurement of the same observable  $A$  will again yield the same result  $a$  with certainty, and after this repeated measurement the system will still be in the same state  $z_a$ . This property, which is also crucial in quantum physics justifies the terminology "eigenstate of an observable  $A$ " for  $z_a$  and "eigenvalue" for the result  $a$ . We emphasize that this is an idealized description of a measurement process abstracting from its detailed temporal structure.

Two observables  $A$  and  $B$  are called *complementary*, if the corresponding measurements are not interchangeable. This means that the state of the system depends on the order in which the measurement results, say  $a$  and  $b$ , were obtained. If the last measurement was a measurement of  $A$ , the system will end up in an eigenstate  $z_a$  of  $A$ , and if the last measurement was a measurement of  $B$ , an eigenstate  $z_b$  will result eventually. For complementary observables  $A$  and  $B$  there will be at least some eigenvalue, say  $a$ , of one

of the observables for which no common eigenstate  $z_{ab}$  of both observables exists. This means that it is not generally possible to ascribe sharp values to the complementary observables  $A$  and  $B$ , although both of them may be equally important for the description of the system. This is the essence of quantum theoretical complementarity which is well defined also for GQT. Some people prefer to apply the term "complementarity" to what we call "maximal complementarity": Knowledge of the value of  $A$  implies complete indeterminacy of the value of  $B$  and vice versa. This holds for the position and momentum observables  $Q$  and  $P$  of quantum mechanics. But according to this definition already oblique components of angular momentum would not be complementary.

Notice, that a measurement will in general change the state of a system by production of an eigenstate of the last-measured observable. This generic quantum feature is realized in a paradigmatic way for the human mind under the first person perspective of self-observation. It will also hold for human thought in general and for all kinds of discourse, belief or decision systems. Quantum features like complementarity and indeterminacy should be common there. Detailed empirical investigations of quantum features in psychological systems have been performed for bistable perception [10, 11, 12], human thought and the formation of concepts [13, 14], apparent irrationality and non-classical logic in decision processes [15, 16], semantic networks, learning and order effects in questionnaires [17, 9]. For further information see [18] There are striking similarities of the measurement process with creative processes [19].

Non-complementary observables, for which the order of measurement does not matter, are called *compatible*. After the measurement of compatible observables  $A$  and  $B$  with results  $a$  and  $b$ , the system will be in the same common eigenstate  $z_{ab}$  of  $A$  and  $B$  irrespective of the order in which the measurements were performed. In classical systems all observables are compatible and possess simultaneous eigenstates, and the phenomenon of complementarity does not occur. It should be clear from our general structural consideration and from the examples given, that this is a strong additional assumption. For general reasons, quantum-like behavior of systems should be the rule rather than the exception.

We also see, how the above-mentioned categorial universals are built into the structure of GQT [8]:

Excentricity is taken into account by the pivotal position of measurement in GQT. In physical quantum theory the epistemic cut is known under the name of Heisenberg cut. Moreover, observables, right by definition, assume the existence of an epistemic cut. They are sitting right astride on it with a footing both on the side of the observer and the observed. Temporality is present in the relevance of the (temporal) ordering of measurements. In addition, quantum systems in general have temporal dynamics. Facticity resides in the factual character of measurement results. Freedom and causality show up in GQT in the strange interplay of freedom in the choice of the observable to be measured

and the causal dynamics of the system.

*Entanglement* can also be defined in the framework of Generalized Quantum Theory [3, 4, 5, 20]. It may and will show up under the following conditions:

1. Subsystems can be identified within the system such that local observables pertaining to different subsystems are compatible.
2. There is a global observable of the total system, which is complementary to local observables of the subsystems.
3. The system is in an *entangled state* for instance in an eigenstate of the above-mentioned global observable and not an eigenstate of the local observables.

Given these conditions, the measured values of the local observables will be uncertain because of the complementarity of the global and the local observables. However, so-called *entanglement correlations* will be observed between the measured values of the local observables pertaining to different subsystems. These correlations are non-local and instantaneous. They are not usable for signals or causal influences. They are non-causal order structures resulting from the holistic structure of quantum systems. The crucial importance of non-causal ordering structures is a fundamental message of quantum theory. The explanatory monopole of causal relations, often tacitly assumed under the influence of a mechanical paradigm cannot be held up.

Comparing Generalized with full physical quantum theory the following vital differences are worth noticing:

- In its minimal version and in contrast to other approaches [21], GQT does not ascribe quantified probabilities to the outcomes of measurements of an observable  $A$  in a given state  $z$ . Indeed, to give just one example, for esthetic observables quantified probabilities seem to be inappropriate from the outset. What rather remains are modal logical qualifications like “impossible”, “possible” and “certain”. Related to the absence of quantified probabilities, the set of states in GQT is in general not modelled by a linear Hilbert space.
- Related to this, GQT in its minimal form provides no basis for the derivation of inequalities of Bell’s type for measurement probabilities, which allow for the conclusion that the indeterminacies of measurement values are of an intrinsic ontic nature. In many (but not all) applications of GQT indeterminacies may be epistemic and due to incomplete knowledge of the full state or uncontrollable perturbations by

outside influences or by the process of measurement. Notice that complementarity in the sense of GQT may even occur as a consequence of different partitions in coarse grained classical dynamical systems [22, 23]. In this sense, GQT is a phenomenological framework theory allowing to leave the question of the ontic or epistemic character of indeterminacies open.

For some applications (see, e.g., [10, 11, 12, 17, 9], ) one may want to enrich the above-described minimal scheme of GQT by adding further structure, e.g., an underlying Hilbert space structure for the states.

### 3 Contextual Emergence

The statistical theory of thermodynamics is often considered to be the classic example of a successful reduction and a well-understood emergence relationship. We already mentioned that emergence concerns the relationship between two descriptions of a part of the world, one of them primary and basic, one secondary and emergent. In this exemplary case the basic level is a system of (many) particles described microscopically by classical or quantum mechanics with the positions, momenta and spins of the particles as fundamental observables. The emergent macroscopic level is described as a system of classical constitution with different macroscopic observables like volume, pressure, temperature and entropy. The macroscopic state is determined by the values of a sufficient number of macroscopic observables. The macroscopic observables *supervene* [24] the microscopic observables because a change in the macroscopic ones is necessarily accompanied by a change in the microscopic ones but not necessarily vice versa. Both the macroscopic and the microscopic description are formally well developed complete theories making emergence and supervenience exemplarily clear issues in this case.

On closer inspection the reduction of thermodynamics to microphysics proceeds in two steps:

First, the detailed microscopic description of states, which is neither feasible nor even desirable for a large system is replaced by a statistical description. This is done by first introducing *mixed states*, i.e. ensembles or sets of pure microscopic states with an attribution of a probability to each of them. In a second step, *macrostates*, defined by the values of macroscopic thermodynamical observable are identified with appropriate mixed states. There are many mixed states without thermodynamic interpretation.

Notice, that the reduction of thermodynamics to microphysics is not to be understood such that in complex microphysical systems after passing a complexity threshold completely new concepts of a thermodynamic description arise automatically by themselves

and from nothing. The concept of probability, applied in the first step is not newly born but pre-existent. It is also applicable to small microscopic systems for which, as opposed to large systems, a detailed microscopic description is still feasible.

Some observables like the total energy are common to the microscopic and macroscopic description. In general, the identification of macroscopic observables like volume and temperature is neither enforced by the microscopic description nor by the concept of mixed states. It comes about by applying different contexts to a section of reality in addition to its microphysical description. For this reason, Atmanspacher, Bishop and beim Graben [6, 7] talk about *Contextual Emergence*.

For a successful Contextual Emergence relationship a further condition must be fulfilled: The mixed states corresponding to thermodynamic macrostates must have a sufficient degree of stability under the microscopic dynamics. Otherwise, these mixed states would quickly develop into mixed states without thermodynamic interpretation. A change of the topology of the states may be necessary to achieve stability.

Thermodynamics is a particularly clear case of Contextual Emergence. There is a widespread hope, that other emergence situations conform with this example. This amounts to demanding a lot: Both the basic and the emergent layer must be well formalized and endowed with dynamics which meet the above-mentioned stability requirement. As for the emergence of a mental from a neuronal description the situation seems to be as follows: For the neuronal layer, a satisfactory formal description is largely available. States and observables are essentially under control, perhaps with some restrictions for the dynamics of larger neuronal assemblies. The situation is much more problematic on the mental level. First of all, we expect it to be organized in a quantum-like rather than a classical manner [18, 25], making reduction to neuronal properties much more difficult. Moreover, there is no comprehensive description and classification of mental states and observables. The dynamics on the mental level can in no way considered to be understood. Exactness is sometimes attempted by restriction to a small set of mental observable, which are, however, so much devised with an eye on the neuronal substrate that reduction becomes almost tautological. The status of the stability requirement is also unclear. Mental dynamics is largely unknown, and one has the impression that on the one hand quite different neuronal states frequently correspond to similar mental states and on the other hand sometimes a small change of the neuronal state often leads to a large change of the mental state. Mental and neuronal properties will correspond to very different topologies and partitions of states. It is just this difference, which makes the "emergence" of a quantum-like mental from a classical neuronal domain possible.

In any case, contextuality will be decisive for neuronal emergentism at least as much as for thermodynamics. The hope for completely reductionist emergentism for the mental domain deriving all mental features in an automatic and cogent way from neuronal ones



seems to be futile.

## 4 Alternatives to Emergence

Emergence and supervenience are genuinely asymmetric concepts distinguishing between a basic, lower, ontologically primary and an emergent, higher, ontologically secondary level. The vision of physical reductionism is a hierarchic structure of the world with a basic physical layer given, for instance, by elementary particle physics and above it a tower of higher stepwise emergent levels like chemistry, life and mind. One may ask oneself, whether such a hierarchic ordering of the world really has an ontological status reflecting a real feature of the world or whether it is epistemic and arises only from a particular description of the world such that in a different description the layers and/or their ordering might be different.

A frequently invoked argument in favor of an ontological hierarchy is concerned with complexity. Emergence arises, when the complexity on the basic layer exceeds a certain threshold. However, one should keep in mind that complexity is an epistemic notion referring to a mode of description. What is complex in one description may be simple in another description. Consider the exemplary case of the emergence of thermodynamics from microscopic mechanics. Experience shows that for thermodynamical systems far from equilibrium the treatment of the fluctuating behavior of the thermodynamic observables becomes complicated to the verge of intractability. In this situation, a microscopic atomic description suggests itself and, indeed, molecular dynamics is the method of choice here. In this case, the direction of emergence seems to be reversed. As a matter of fact, thermodynamic fluctuations were historically one important reason for the acceptance of atomism.

Contextuality of emergence and the high degree of autonomy of the emergent level are further arguments against an ontological hierarchy. As an example, the function of a software is largely independent of its underlying hardware substrate realization and could be achieved in many different ways. It is also conceivable that mental properties could rest on a basis quite different from neurons. As far as physics is concerned, it is quite uncertain, whether a really fundamental level has already been reached and whether it exists at all. In addition, recent developments seem to indicate that elementary particle theory is not understandable without and closely interwoven with cosmology, which according to the traditional view should emerge from particle theory.

From the preceding considerations we see, that the ontological status of the emerging layer is quite strong and independent and not strictly subordinate. Moreover, an ontologically hierarchical order of the world is disputable. In this situation it is suggestive to question

the asymmetry inherent in the concept of emergence with the distinction between basic and emergent layer. Emergence is a relationship between two formal systems with different sets of states and observables both of them describing a certain sector of reality. Neural emergence with a basic neuronal and an emergent mental layer is the example of central interest for us. A more symmetric alternative to emergence in general and neural emergence in particular would be *extension of the set of observables* or more briefly *Observable Extension*. This amounts to describing a sector of reality by just one formal system with one large set of observables corresponding to both layers of emergence. For example, rather than neuronal emergence, one considers just one large comprehensive system "man" or even "man plus physical and social environment" which contains both neuronal and mental observables. This is in accordance with a standpoint of neutral dual aspect monism with respect to the matter-mind problem. We already saw that complementarity should occur between mental observables of the comprehensive system. One can also argue that complementarity between neuronal observables on one side and mental observables on the other side should be common [25]. So, in any case, the comprehensive matter-mind system should be quantum-like in the sense of GQT.

For "Observable Extension" contextuality is at least as vital as for Contextual Emergence. The identification of additional observables is not automatically enforced by the other observables but corresponds to the introduction of new concepts and contexts into the investigation of the comprehensive system.

For complementary observables different values for one of them will in general change expectations for the measured values of the other one. So, the basic dictum of supervenience "Change on the emergent layer leads to change on the basic layer" also holds for complementary observables in an appropriately symmetrized form.

## 5 Conclusions

We are now in the position to attempt answers to the three questions raised in the Introduction.

The first two questions concerned the ontological status and the novelty of "emergent" properties. It should be abundantly clear from the preceding considerations, in particular from the analysis of the paradigmatic case of the emergence of thermodynamics, that contextuality is a vital element in the discussion of emergence. It is even more central in the symmetric alternative concept of "Observable Extension". Unless one is willing to adopt a radical eliminatory reductionism, the "emergent" properties are not automatically generated by the "basic" layer beyond a certain threshold of complexity. Rather they come from different contexts becoming applicable or useful. Finding such contexts and

detecting their applicability is a subtle achievement of creativity whose origin is a deep and difficult question [19]. As for the novelty of the "emergent" features: They are not suddenly born from the basic layer like Athena from the head of Zeus but they correspond to preexistent notions and the novelty consists in their applicability or usefulness with increasing complexity on the basic level. To give a very simple example: If the complexity of a system of points in a plain is increased from two to three points the concept of angles becomes applicable and useful, but it was already existent and not newly born with the appearance of the third point.

The third question raised in the Introduction was about "downward causation" from the emergent to the basic level. It is formulated in a slightly provocative way as *Kim's Dilemma* [26]. For the status of the emergent mental level in relation to its neuronal basic the following dire alternative seems to hold: Either mental properties are just abbreviations for neural properties in the sense of an eliminative reductionism or else, due to the assumed causal closure of the physical world, they are impotent and causally decoupled from the physical world. This leads Kim to the assertion that emergence and supervenience are formulations rather than solutions of a problem.

The assumption of causal closure of the physical world is questionable [2]. But even taking it for granted, a smooth resolution of the dilemma comes from the concept of contextuality both in the form of Contextual Emergence and of "Observable Extension". There is no causal interaction between the neuronal and the mental level and, in fact, no such interaction is needed. The relationship of the different layers is not causal in its nature but a correspondence and order structure, which is due to the fact that the same part of reality is observed from different perspectives. From the example of the emergence of thermodynamics we easily see that the relationship between the microscopic and thermodynamical description is not a causal one. Of course, the microstate changes when the values of thermodynamic variables change, but this simultaneity in change only reflects the fact, that both descriptions are different sides of the same medal. This becomes even clearer if we consider complementary observables in one and the same system. Nobody would interpret the subtle relationship between position and momentum distributions as causal effects.

Kim's dilemma just results from an unjustified monopolization of causal relationships as explanatory structures. Quantum theory with its inevitable non-causal entanglement correlations lends yet another disproof of such a one-sided claim.

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